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EDITORIAL

Recent advances in the analyses of directional data in ecological and environmental sciences

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Directional data (DD) generally refer to data on angular propagations or displacements, orientations, directional movements, etc. Periodic data, such as those recorded on hour of the day, day of the week, etc. can be viewed as and are also cast in the arena of DD through transformations to representative angles. The DD are encountered in all areas of applied sciences, presumably more prominently in ecological and environmental sciences (EES).

Research on paleoenvironment often necessitates the hind-casting of directions of river flows obtained from the azimuthal direction of the current that formed the cross-beds. Significance of multimodality of cross-bedding orientations suggests multiple paleoperiods corresponding to varying transport conditions. Orientations of poles to beddings constitute three-dimensional directional data. Directions of remnant magnetism on rock cores are important data in paleontology and earth sciences, e.g. as in the study of reversal of polarity of earth. Studies on the directional movements of ice-floes and ice-bergs are indispensable for planning of transport and of routing of ocean-liners on the confused seas and oceans. Variations in the flight directions of migratory birds form the basis of the evolution of new migratory routes. Displacements in the wintering trajectory of migratory species in search of new breeding areas for colonisation or in their subsequent homing directions are important predictors of environmental and ecological changes. Such a change is often attributed to microevolutionary processes and also to possibly a selection from the earlier used list of genetically based migratory directions. These also lead to changes in the size of the wintering population as well as suggest the mode of the way of inheritance. Corresponding directional measurements may be obtained from ring recoveries, cage experiments or satellite-based radio telemetry. Peak directions of dissolved oxygen, pH value, algae concentration,

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etc. shed light on the regions of the lake or of the controlled ecological conditions leading to the maximization of the growth rate of fish. Orientations of nesting directions of birds in relation to the direction of flow of an adjacent creek, directions of movements of insects when faced with an object attracting or repelling them, swimming directions of aquatic creatures in search of their spawning or breeding zones, etc. are yet some more examples of circular data in ecology. Periodic or cyclical data such as time of the day itself, is a circular predictor of pollution index. Viewed in another way, daily peak times of temperature and of wind speed, etc. are circular variables with important bearings on the pollution level. Another variant of DD is axial data which arise from processes generating, e.g., undirected lines, lines with unidentifiable origin and end, orientations incapable of discriminating between angles 180° apart, etc. Examples of axial data are observations on propagations of cracks in concrete, metal or mining walls, orientations of feldspar laths, etc.

Due to the disparate topologies on the line and on the circle, usual procedures, which have been developed for analyzing linear data will not be meaningful and will be misleading when applied to analyze DD. Some methods specific to DD have thus been proposed. Many of these are intuitive and /or ad-hoc (see e.g. Mardia 1972, 1975; Batschelet 1981; SenGupta 1988; Jupp and Mardia 1989; Upton and Fingleton 1989). Also, the implementation of exact or small-sample procedures for DD invariably calls for non-trivial computations, often computer intensive. This has been a deterring factor for the use and further development of many such procedures. The advent of computers has resulted in a flurry of new results on both the theory and applications of DD. Within a span of less than two decades, at least five books/monographs on DD have emerged (e.g. Watson 1983; Fisher et al. 1987; Fisher 1993; Mardia and Jupp 2000; Jammalamadaka and SenGupta 2001). The DDSTAP (SenGupta 2005), the first platform-free and stand-alone statistical package for the analysis of DD, has been just released. The impressive and ever-increasing list of recent publications, both in volume as well as in the diversity of applications, bears evidence to the increasing need and popularity of modern techniques for analyzing DD. This fact was one of the motivations for preparing this issue. The other, and more important, motivation was the crucial role played by DD in EES as exemplified above.

Contents of this issue give glimpses of the richness in diversity and the innovativeness in methodology called for to analyze DD encountered in EES. Twelve authors have contributed to the six invited papers constituting this issue. Starting with as basic a problem as of defining descriptive measures for the preferred direction in circular data, the issue goes on to deal with as complex a problem as of developing time series models for possibly multi-modal cylindrical data. Each paper emphasizes on real-life applications from EES. The papers in this issue may be broadly summarized topicwise (not necessarily in the order of their appearances) as follows.

(1) Three measures of the preferred direction, including a newly proposed circular analog of the Hodges–Lehmann estimator are discussed and are illustrated with data from EES. It is demonstrated that the choice of the appropriate measure may be dictated by the presence of outliers or skewness in the original data. These measures were applied to study the homing directions of pigeons displaced from their lofts, the use of sun-compass by topiminnows displaced from their natural habitat and the directional movements of *Nodilittorina unifasciata*, small blue periwinkles, transplanted downshore from the normal height of their homes.

(2) For skewed circular data, the wrapped skew-normal distribution is studied as a model and some important related inference procedures are developed. The methods developed are applied to a real data set from the ornithological literature. The data, consisting of the 'headings' of a group of 1,827 presumably migrating birds, strongly suggested asymmetry and possibly multimodality for preferred direction. The latter aspect may be attributed to the situation that the group consisted possibly of several different species and/or of both migratory and non-migratory birds. A mixture model with an asymmetric component is envisaged here and estimation and testing problems related to its parameters are discussed.
(3) Dependency between circular and linear variables are often studied through methods based on circular correlation and circular regression. As an illustration of dealing with environmental issues, a case study on how the wind direction plays an important role in determining the ozone levels, in a suburb of Houston, is presented exploiting these methods.
(4) Motivated by the need to predict certain environmental characteristics based on some circular (and linear) predictors, which exhibit possibly asymmetric dependency structures, asymmetric angular-linear multivariate regression models are proposed. These models are then applied to two data sets. For the first data set, the problem of predicting the absorber temperature in a Thermosyphon solar water heater based on the circular variable time (in hours) and two other linear variables (ambient temperature and control temperature) is considered. For the second data set, two circular variables—time and wind direction, and the linear variable—wind velocity, were used as predictors for predicting the wind energy generated.
(5) Moving on to data on other manifolds, a new approach is proposed to model axial data. Axial probability distributions are constructed using this model and procedures for certain related statistical inference problems are developed. This approach is illustrated through two data sets, one on face-cleats in a colliery and another on long-axis orientations of feldspar laths in basalt.
(6) Finally, novel and new approaches through hidden Markov models are introduced, with a good degree of flexibility on the underlying family of distributions, to analyze possibly multi-modal circular and bivariate linear-circular time series data. Bivariate linear-circular time series are quite common in EES, as with observations on, e.g. the speed and the direction of wind or ocean current, temporal recordings (usually noted aerially) on the extent of the movements of a wild animal, the daily peak time and the corresponding load of a pollutant, etc. The proposed models have been implemented to analyze a meteorological data set as also to describe larval movement of the fly, Drosophila.

We hope that this issue will provide the researchers with both the fundamental and modern insights and enable them to embark on new and innovative techniques for rigorous statistical analysis of DD in EES.

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